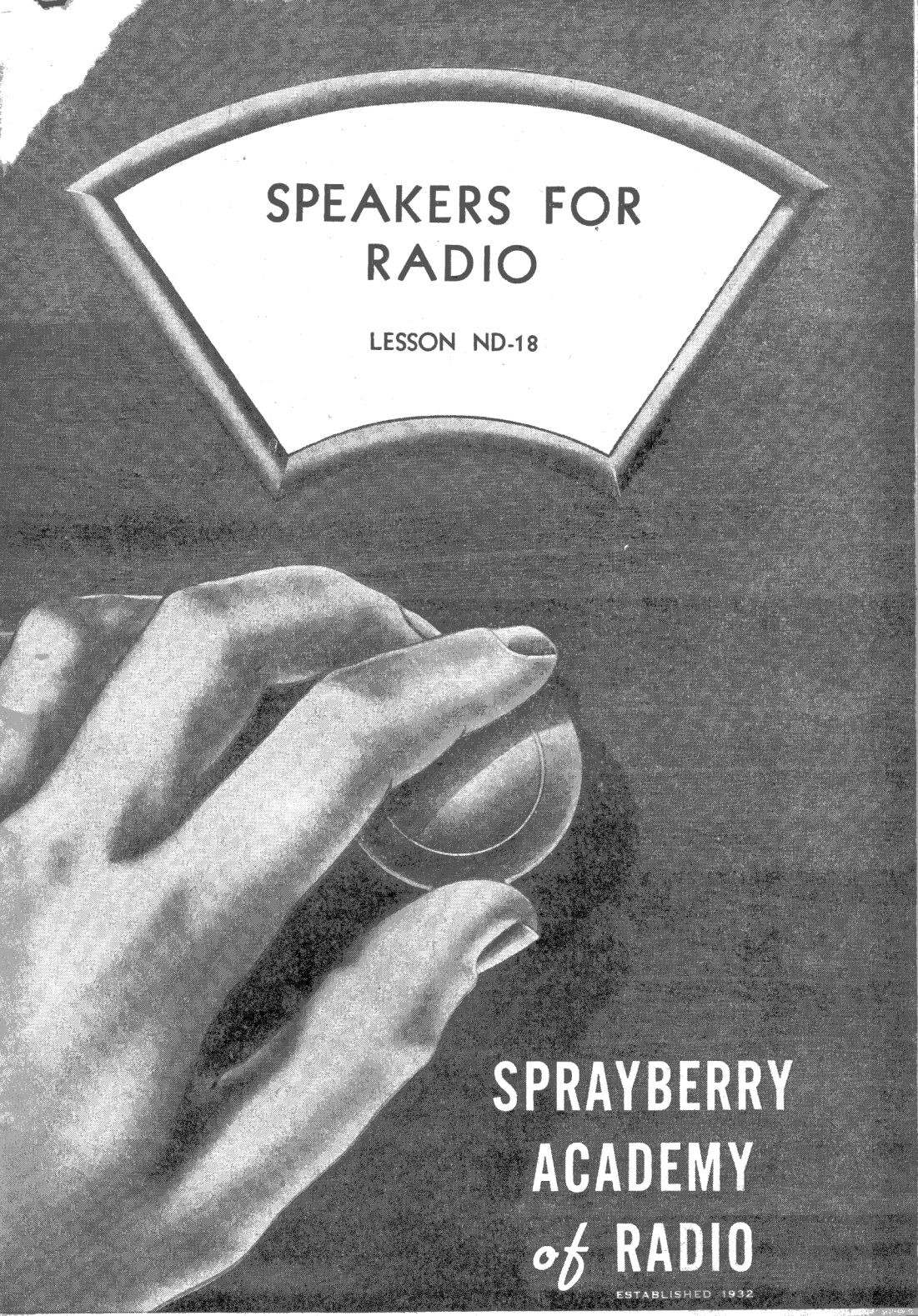
SPEAKERS FOR RADIO

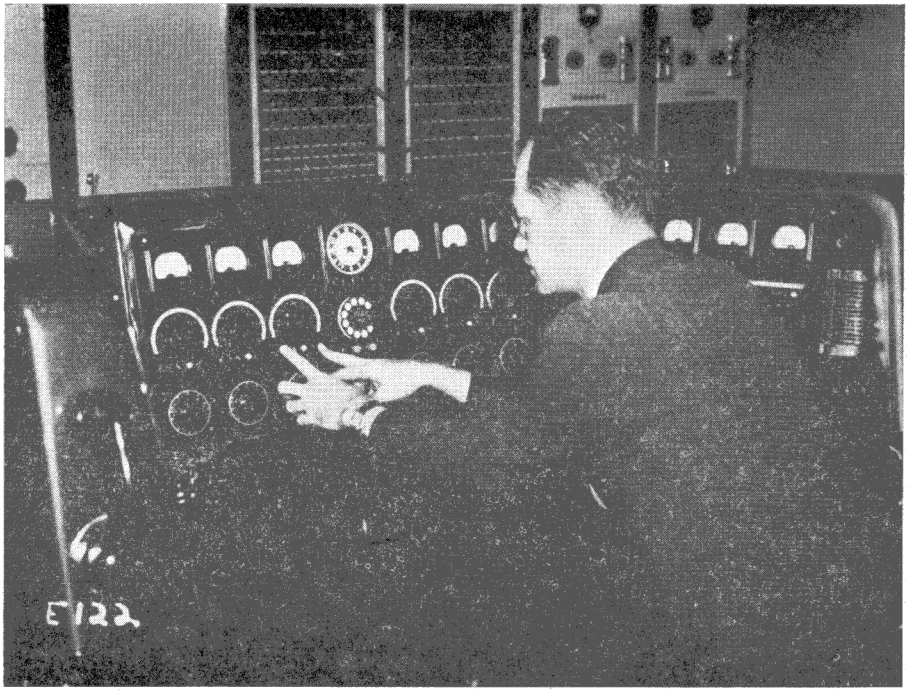
LESSON ND-18



SPRAYBERRY ACADEMY of RADIO

ESTABLISHED 1932

PUEBLO, COLORADO



The above view shows the controlling point for all sound energy before it reaches the radio set. It is the control panel of a powerful radio transmitter. Courtesy of Westinghouse.

SPEAKERS FOR RADIO

LESSON ND-18

Up to this point you have studied the principles of how a radio signal is received, amplified and detected before it is applied to a reproducer or speaker to form sound waves. The signal is greatly magnified (amplified), rectified (detected) and perhaps transformed in other ways, depending on the circuit through which it may have passed, until finally it is in the form of a current flow of varying intensity corresponding exactly to the original variations of air pressure on the microphone at the transmitting studio. This varying current is thus described because it may either be direct current of varying intensity or alternating current depending entirely on the type of speaker used and the method of coupling to the output tubes of the receiver.

One of the first devices used to convert electrical energy into sound waves was the headphone. Vertical and top section views are shown in Figs. 1 and 2. Two iron core spindles of wire are mounted on either end of a semicircular permanent magnet mounted in the base of the unit and each is wound with several thousand turns of very fine wire. Their

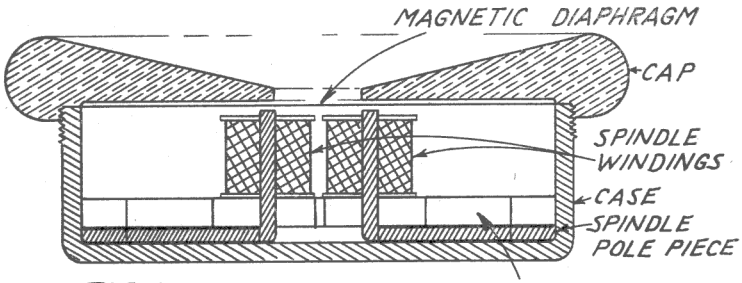


FIG. 1

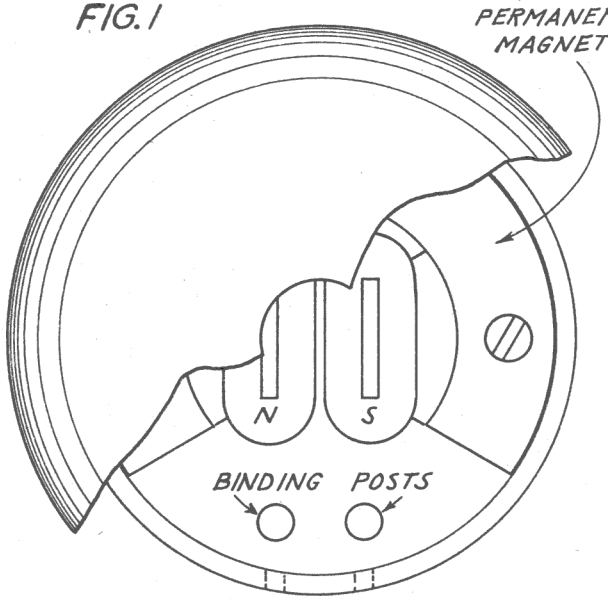


FIG. 2

tops are spaced about one-half inch apart and the shell of the unit is made to support a magnetic metal diaphragm over the spindle magnet poles, leaving a small space equal to about two or three thicknesses of ordinary paper between the pole pieces and the diaphragm. The magnetic circuit is completed from the *north* to *south* pole of the magnet as shown in Fig. 3. An insulated cap is arranged to screw onto the case and binds the outer edge or circumference of the diaphragm firmly and also serves to guide the sound waves to the ear. The wire windings are connected in series and polarized so that each will aid or oppose the magnetic pull on the diaphragm. The ends of the windings are fastened to binding posts on the earphone housing to facilitate connection of the cord which carries the electrical energy from the receiver to the headphones. The cords are special light weight and extra flexible conductors, one end equipped with convenient *phone tips* and the other with spade or round washer type terminals.

When a current flows through

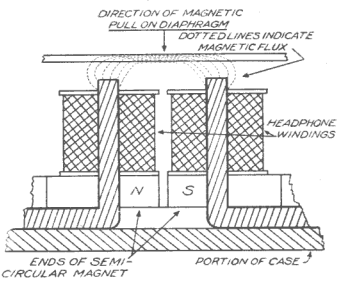


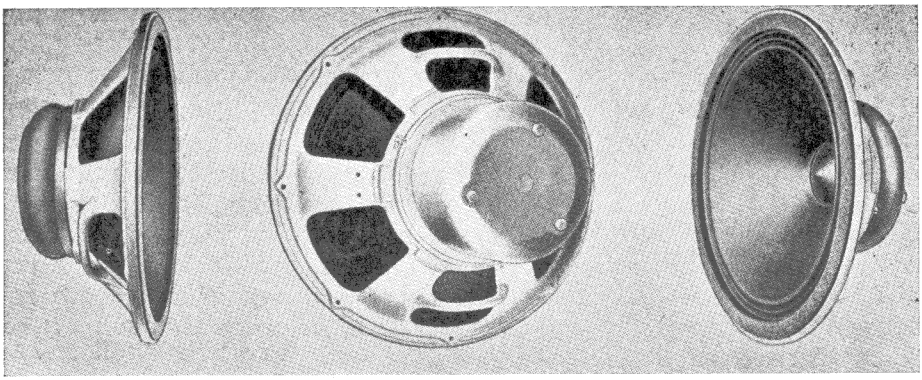
FIG.3

the windings in such a direction as to add magnetism to the magnetic loop, the diaphragm is drawn in toward the spindles and when current reverses, it has the effect of subtracting magnetism from the loop, the diaphragm is thus allowed to return to its original position. Magnetism induced through the spindles by the permanent magnet tends to hold the diaphragm in a position slightly flexed toward the spindles. The diaphragm being clamped around its outer edge is pulling against this attraction tending to return to its normal flat plane. Thus the diaphragm is constantly attracted by the pole pieces but this attraction will vary as the current in the windings varies. If the current through the windings is in such a direction as to pull the diaphragm in, it will bend *less* when the current is reduced, removed or reversed. It is necessary to use a permanent magnet in the unit so that the tension on the diaphragm will always be exerted in one direction although its intensity will vary according to the current flow through the unit. The construction of this unit prevents the possibility of there being a repulsion force on the diaphragm except for its natural flexibility, so reversing currents instead of attracting and repelling the diaphragm, simply attract, and leave it free to flex as the current alternates or varies.

Now if the current supplied to the phone windings has values which are exactly equivalent to the values of energy in the original sound waves which produce them, this current will change its intensity in the correct fashion to reproduce the original sound.

Sound is produced by compressing and rarifying air rapidly by a moving or vibrating body such as a thin diaphragm. When a body such as a diaphragm moves forward rapidly, the air immediately in front of it is crowded as the diaphragm is occupying space formerly taken up by air. This crowded or compressed air tends immediately to expand into the surrounding air which is at a lower or normal pressure, and, in so doing, it must compress air all around it. Now if there are no walls to confine it, this crowding process will continue to push itself on to more and more air until the space it occupies is so large that its energy is exhausted or until the process dies down due to friction of the air particles. This movement of energy of the air due to the original compression travels through normal air at a velocity of approximately 1080 feet per second, and, if it takes place rapidly, it forms a wave *and will produce the sensation of sound.* That then is the purpose of the thin diaphragm commonly used with headphone units.

Since the amount of air that could be moved by this relatively small headphone diaphragm as well as the distance through which



The above photo shows three views of dynamic speakers. They are available in either electro-dynamic form or in permanent magnet form. Courtesy of Cinaudograph.

it could move were quite limited, larger diaphragms with greater movement came into rapid use. The amount of energy that can be dispensed as sound depends on the amount of air that can be set in motion. A larger surface can set more air into motion just as a larger boat oar can get a better grip on the water. Likewise, a long oar can dispense more energy than a short one in one stroke as can a diaphragm that moves through a long stroke or cycle.

The first actual speakers to make their appearance on the market were simply horn attachments made as improved and enlarged units of the same general character as that of the headphone. These were usually attached to phonograph horns and later were sold with various type of horns attached. Later designs included *exponential* horns about which you will study later.

MOTOR TYPE OF SPEAKER

Figure 4 shows a cross section of a typical actuating mechanism used in what is fequently called the *motor* type of speaker. The use of such a device enabled the driving of larger diaphragms producing more volume of sound because of the greater amount of air that could be set in motion.

At this point it would be well to point out that as the diameter of flat diaphragms is increased so is the amount of air displaced. However, when force is applied to the center of a large flat diaphragm, only the center moves and a great percentage of the surface is useless. Since a *cone* is a geometrically solid structure, if a suitable driving force is applied to the *apex* of the cone the entire structure will move thus displacing a greater quantity of air than an equal diameter flat disc will move. Since, by using a cone, stronger sound waves could be produced, a method of driving these cones with a total back and forth motion greater than the motion created in the

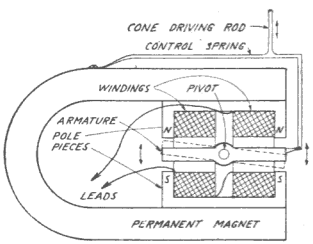


FIG. 4

headphones was sought. This led to the development of the motor type speaker.

Referring to Fig. 4 you will notice that an armature is suspended at its central point on a pivot in order that each end of the armature is equidistant from the poles of the permanent magnet. This pivot is so placed that the armature is in the center of the armature coils in order that any current flowing in the coils will magnetize the armature to an extent practically proportional to the current. As the armature is made from especially *soft* iron, it will not retain magnetism permanently. This is a *necessary characteristic* as the current in the coils may reverse as often as 20,000 times a second, and if the armature did not change its magnetic polarity equally as fast, some of the pulsations would be lost, thus introducing distortion.

For the reproduction of higher frequencies (high musical tones), the current in the windings changes its value very rapidly, and the magnetism of the armature changes in a like manner. The more rapidly this alternation occurs, the more rapidly the armature must reverse its direction of movement. Thus, its distance of movement or amplitude, as it is called, is reduced. The armature is made as light in weight as possible, as well as the moving parts to which it is connected so that the self-inertia (dead weight or mass effect) of the parts does not prevent free movement through as large an amplitude as possible. Practically all of the energy from the magnetism of the field magnets working with the armature is converted into mechanical energy and this is used to move a cone. This cone pushes (compresses) the air and rarifies it almost instantaneously. Current flow through the windings will magnetize the armature to a degree practically proportional to the current. The armature thus becoming magnetized will be attracted by the *unlike* pole pieces of the permanent magnet and repelled by the like poles according to basic magnetic laws which you studied in an earlier lesson. Notice how these *basic* laws which you have studied gradually come into use throughout your lessons.

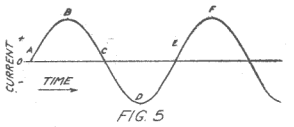


FIG. 5

The A.F. current conducted through the armature coil may be pictured somewhat as in Fig. 5. This is considered, for the sake of simplicity of study, as a pure tone of constant value, both in amplitude (strength) and frequency (pitch). As the current rises in the positive direction as indicated between points A and B, the armature of the speaker is drawn toward one of the poles in just this manner. That is, at first rapidly and then more slowly in a regular manner until the current at B rises no more and the armature moves no more. However, from B to C, while the current drops, the armature gradually returns to its neutral position, arriving there at the same time that the current reaches C. The current then reverses and increases in the reverse direction as indicated by the curve from C

to D, forcing the armature by magnetic attraction to follow it as before. The two windings are connected in series in such a way that they aid each other in magnetizing the armature with a given polarity. In one direction, the current through the windings will move the left end of the armature to N and the right to S; this will move the armature clockwise and pull the cone driving rod down. When current moves in the other direction, the left end will then be attracted to the S field pole (the lower one in this case) and the right end will seek the N pole of the field at that end. Thus, the armature will move counter-clockwise and push the cone driving rod up.

It may be readily seen that if the rod can move up 1/8th inch and down this much, too, its total latitude of motion will be 1/4th inch.

Some of the early horn type speakers used this motor with a disc diaphragm having circular corrugations in it to make it bend very easily and through a large latitude. The more flexible the diaphragm, the greater the tendency of it to bend at the point where the mechanical motion is applied and so move the entire surface very little. The more rigid it is made, the less it will move at all.

The cone diaphragm therefore has a very considerable advantage over the other type (flat diaphragm) because the entire cone will move without bending. Thus, its latitude of motion has no practical limit, and it can be made as rigid as necessary. Note that the armature in Fig. 4 is connected to a control spring by a small rod. The function of this spring is to return the armature to its balanced position after a fluctuation of current causes it to move. The spring also serves as part of a system of levers for the reason that the amount of *power* available from the armature varies as its motion varies—its motion might not create the amount of motion or power required by the size and weight of the cone. To *lessen* this motion and *increase* the power, the cone driving rod is located at a carefully selected point on the lever formed by the spring. This enables the matching of the power and motion of the armature to that required by the cone.

The driving rod is attached to the cone at the center by means of two conical collars with a nut binding it on either side. See Fig. 6. Thus the driving pin moves the entire surface of the cone at the same time. Sound waves emanate from each side of the cone in equal intensity and hence there is no standard practice of placing the motor on the concave or convex

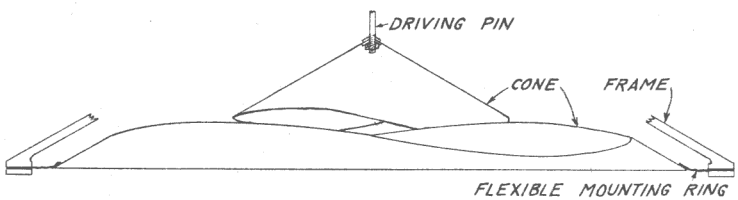


FIG. 6

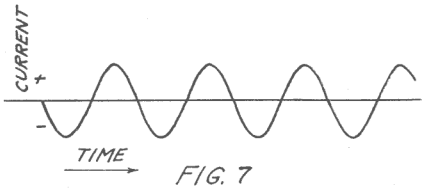


FIG. 7

side. For reasons of space conservation in an exposed type speaker, that is, one not housed in a cabinet, the motor is usually placed in the concave side of the cone where it is out of sight; thus, the whole speaker requires no more space than the cone alone.

Cones are generally made of heavy paper or parchment of a prepared variety and as flat as will be consistent with rigid structure. Since they must move as much at their edge as at their center, a very flexible cloth or chamois is used to support the edge of the cone to the frame in which it is mounted. Some of the earlier type cones were left entirely free at the edge being supported from the driving pin as well as being driven by it. The material used for the edge support is porous and sound absorbing and does not contribute to the production of the sound in any way.

For the moment, disregard the qualities of sound by which you may identify the instrument which produces it and consider a curve as in Fig. 7 representing middle C on the piano or any other instrument. The diaphragm of the speaker moving in this manner will then reproduce this tone. If added to this sound there is a violin tone having, for example, five times the number of vibrations per second, a wave which may be represented as in Fig. 8 will be produced; if they are both acting on the diaphragm simultaneously, it will respond to only *one* wave, which will be the resultant of the two sound waves mentioned. The resultant *single* wave will appear as the heavy curve in Fig. 8. As individual waves, the dotted lines are entirely lost, their energy combining to make the one wave shown by the solid line. *In the same way, any number of sounds will combine to form a single wave at one point* (the microphone or other pick-up device), and this resulting wave will be transmitted. This explains how a single needle point of a phonograph pick-up can reproduce the sounds of a 50 piece orchestra and how a single diaphragm, which can only occupy one position at any one instant, can do the same thing.

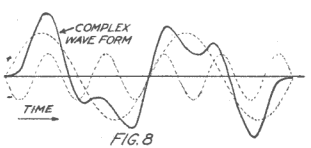
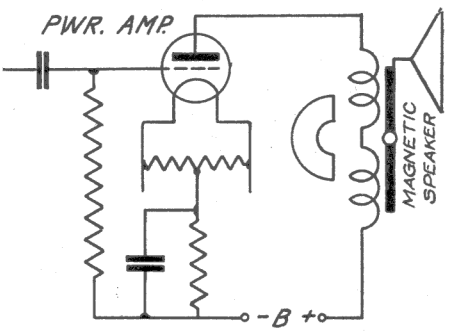


FIG. 8



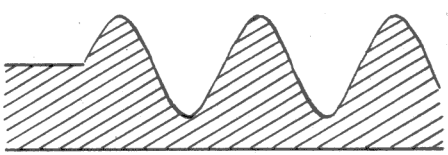


FIG. 9

Therefore, only *one wave* need be considered for if this can be reproduced, it is possible to reproduce any sound. Of course the sound wave may be very complicated, but as long as any tone in the audible spectrum can be utilized at reasonable volume, any sound recognized by the human ear as such can be reproduced.

Refer to Fig. 9, and note that the speaker armature windings conduct the plate current of the output tube. This is constant direct current when no signal is be-in fed to the grid of the tube. If the armature of the speaker was adjusted at the factory in the exact center of the gap in the field poles, this direct current through the armature coils, no matter how small, will pull the armature off center. The control spring will be under tension and when the armature swings back and forth under the influence of a signal it will be more difficult to move in one direction than the other. This will cause distortion or flatness of tone. In most cases, the adjustments provided for the armature will permit readjustment in the exact center, but, if not, the speaker must be connected so that it carries no direct current at all.

Another important consideration is that if the armature coils must carry, say 20 milliamperes with no signal, they must carry nearly 40 milliamperes when the signal current instantaneously adds to the direct current. The windings may not be able to carry this much current and need not do so if connected differently. The speaker can be made to operate with exactly the same volume while

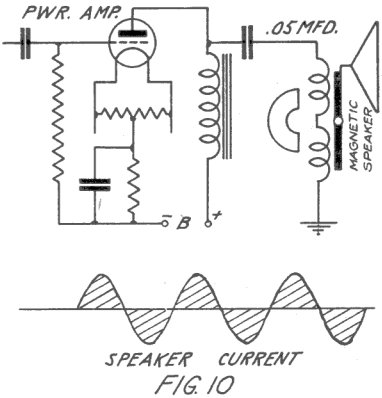


FIG. 10

carrying no more than 20 milliamperes maximum.

A connection as shown in Fig. 10 will permit the speaker to operate in this way. As the D.C. is blocked or prevented from entering the speaker circuit by the condenser C, the zero signal adjustment of the speaker remains unchanged. When the A.C. signal is fed to it, the armature swings equidistant about its true center position with no distortion. This gives the armature just twice the latitude in which to swing because it may swing its full amplitude in either direction, whereas before it could swing only on one side of center lacking any reverse current to allow it to swing in the opposite direction. It may be easily seen that almost twice the volume can be obtained in this way and with no distortion inherent in the speaker because of improper connection or adjustment. Even if the armature may be perfectly adjusted when connected, as in Fig. 9, the amount of D.C. which it will carry will change with aging of the tube and will leave the speaker out of adjustment. Thus it is wise to avoid the connection in Fig. 9 whenever possible. Proper con-

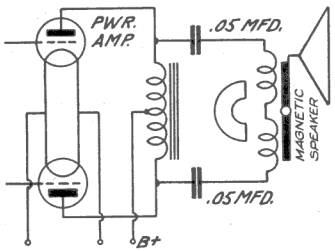
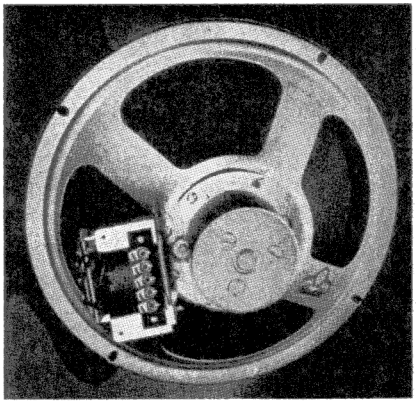


FIG. 11

nections for push-pull operation are shown in Fig. 11.

If it is necessary to replace the diaphragm of any magnetic type speaker, be sure that the new one, or the old one repaired, is mounted so that the motor spring is under no tension and that the drive rod is not twisted or bent in tightening. This will alow free motion. Be sure too, to remove all metalic particles from the motor, as the smallest bit of metal between the strong magnetic field poles and the armature will cause distortion. Do not let the speaker be operated with so much volume that the armature may touch the pole pieces as this will cause distortion of reproduction. If the diaphragm is warped or twisted or under any kind of stress, it may vibrate in some *auxiliary manner,* causing serious distortion. Your S.A.R. Master Service Course lessons will give all of the details on speaker repair.

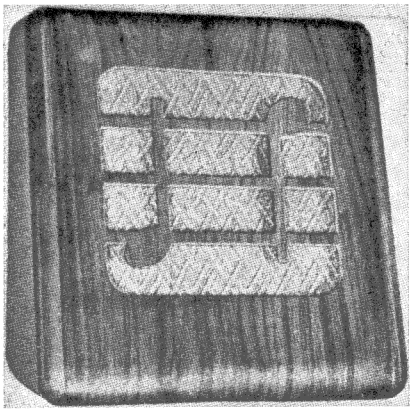
The power that the output tube amplifies and passes on to the speaker for transferring into sound (reproduction of the original sound at the studio) is of a very definite variety. Depending on the output tube which is used for this purpose, the power is available at a certain maximum voltage and current. Of several tubes pro-



This is a rear view of a permanent magnet, 12-inch cone speaker. Note the output transformer mounted on the frame of the speaker. Courtesy of Atlas Sound.

ducing the same power in watts at the output all may produce this power at a different voltage and, subsequently, current. One speaker cannot make use of the maximum power of all of them and hence the speaker must be utilized with the properties of the tube in mind. If not, then some means must be employed to make use of as much of the power delivered by the tube as possible. For the best conditions of transferring the power from the output tube to the speaker, the latter must be able to take the same voltage and current that the tube provides. A single measure of the ability of the speaker and also of the tube to do this is the *impedance measure* of both of them. That is, if the impedance of the speaker is the same as the output or plate impedance of the tube, a maximum of power will be transferred to the speaker.

If the voltage produced by the tube at the output is the same as the voltage required by the speaker for maximum operation, and the respective currents are the



Speakers are used in various forms. The above view shows a wall type speaker which may employ either a PM or electrodynamic unit. Such speakers are used in taverns and in recreation rooms. Courtesy of Atlas Sound.

same, then it follows that their impedance must be the same. This is true because the impedance is equal to the voltage divided by the current, and they are the same in either case. They need not be the same if they bear the same ratio in each case. It may be seen that the impedance in this case would remain the same. The exception to this rule lies in the reproduction of minimum distortion. Usually, as you have learned, a tube is matched to an impedance somewhat higher than its own A.C. plate resistance.

Considering a type 71A tube, for example, with a plate impedance of 1750 ohms, there must be used with it a load of 4800 ohms for maximum undistorted output. A speaker must be selected with this amount of impedance or some other device must be used which will properly couple the tube to the speaker so as to maintain the desired impedance ratio. The ideal device for this purpose is a transformer as it is possible to have any impedance in the primary and the same or any other impedance in the secondary winding and yet transfer a maximum or optimum of power from one to the other The reason for this is that the energy is changed from current flow to magnetism and back again in transferring power from one winding to the other. In this way the impedance may be raised or lowered to any degree desired for a speaker. The two windings of a transformer are always matched, as the magnetic equivalent to the electrical impedance is always matched to both windings.

Since most speakers of the magnetic type have impedance values of around 4000 ohms average, this figure will make a good example. In coupling such a speaker to a type 71A tube, as shown in Fig. 12, a transformer having a primary impedance of 4800 ohms (to connect to that of the tube) and a secondary impedance of 4000 ohms (equal to that of the speaker) should be used. Note, also, that there is no D.C. in the secondary circuit accomplishing, as well, a solution to the former D.C. problem. This transformer would have a slight step-down ratio. Conversely, if the tubes were matched with less impedance than the speaker, a step-up transformer of the proper ratio must be used.

The coupling transformer must also have at least a power rating

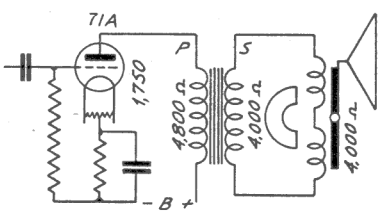


FIG. 12

equal to that of the maximum power of the one, two or four tubes from which it feeds. To determine the ratio of wire turns for any transformer for use when the input and output impedances are known; divide the large impedance by the smaller and extract the square root of the dividend. For example, consider an input impedance of 7000 ohms and an output impedance of 500 ohms. 7000 divided by 500 equals 14. The square root of this is 3.74, (approximately) which is the ratio of the transformer. That is, one winding (the one with higher impedance) has 3.74 times as many turns of wire as the other. If one has 1000 turns, the other has 3740 turns. Figure 13 shows the proper connections for a push-pull circuit employing an output coupling transformer to the speaker.

As a radio repair man is often called upon to add other speakers or headphones to the output of receivers and amplifiers, the principles outlined above should be thoroughly studied. Successful output matching to the reproducers involved is a vital necessity for volume with good quality. More will be studied about this interesting subject later in this lesson, after you have become acquainted with other types of reproducers.

Incorrect choice of output transformers will result in very evident distortion and loss of some frequencies. This, of course, would render useless all the careful engineering in the transmitter as well as in the receiver. For this reason you must always be very particular when replacing or specifying any output coupling. Then, too, the size of wire in a theater installation, for instance, between the speaker and its coupling transformer must be chosen so as to have a low current loss (particularly if the output transformer is in the projection booth). If the transformer is located at the speaker on the stage it means that the high voltage plate wiring will have to be carried from the projection booth to the stage. If the proper choice of conductors is not made, the capacity (condenser action) between the wires of the conductor will act as though a condenser had been placed across the winding of the transformer, thus shunting a portion of the voltages of that winding. There are methods of overcoming these difficulties and you will study some of these in a later lesson.

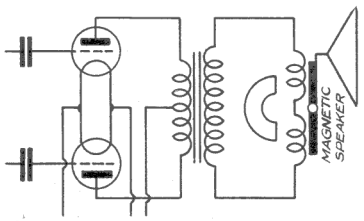


FIG. 13

As you have no doubt realized, it would seem a simple development to build larger cones or diaphragms and design larger motors to drive them. The engineering problems are quite complex, and the big problem concerns the weight of the moving parts and their *inertia*. It is a fact that the motor type speaker has been superceded by other types in which the inertia of the moving parts is lower. Another fault of the motor speaker is its tendency to possess *natural* periods of vibration. In other words, due to the *mechanical*

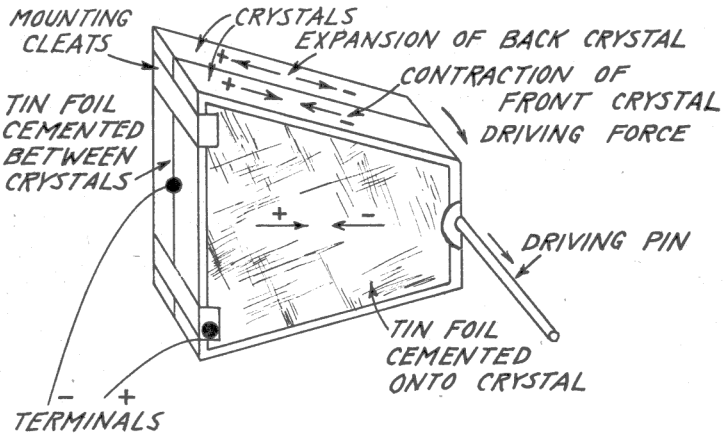


FIG. 14

resonance of the spring and the *dead* weight of the moving parts, these speakers will vibrate loudly at some frequencies. Thus they will require a great deal more power at the other frequencies. Under this condition some sound frequencies will not be reproduced at all due to combinations of the foregoing limitations.

Other types of speakers have been developed which do not posses *as many* faults as the motor type. The first of these to be described uses a non-magnetic motor and is usually termed a *crystal operated reproducer*.

CRYSTAL OPERATED REPRODUCER

The tendency of certain crystals to respond to a voltage by expanding or contracting in actual size has long been known. They also have the ability to produce a voltage when a mechanical pressure is placed upon them. Crystals made of quartz are used for oscillator generators of A.C. requiring frequency stability, but quartz has only a small *piezo-electric* (see your S.A. R. dictionery) effect. Tourmaline and Rochelle Salts crystals have much greater piezo-electric effects and are used in microphones, phonograph pick-up units and speakers.

To get the maximum advantage of this ability to expand or contract when a voltage is applied, special mechanical construction is required. Two thin crystals prism shaped, as in Fig. 14, are cemented together with a thin layer of conducting metal foil (common tin foil may be used) between the two crystals which is used as the first terminal or speaker electrode. On the outside of each of these crystals is cemented other foil coverings. The foil on the outside surfaces of the crystals are connected together, making in common the second terminal, or speaker electrode. When the signal is fed to these two terminals with the instantaneous polarity indicated in Fig. 14, the front crystal will contact along the line marked by the arrows. The other crystal is so cut and placed that it will, at the same time, expand along the lines shown for it, and, since the two crystals are cemented together,

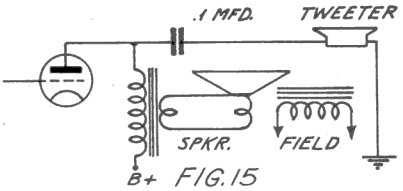
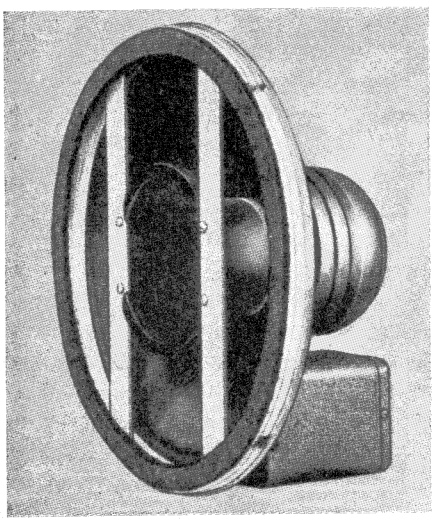


FIG. 15

they will cause the whole unit to bend. The left edges are held rigid so that in bending forward the front crystal will expand and the back crystal will contract, causing the driving pin to move backward.

Appreciably no effect is to be had with such a speaker below 100 cycles. However, the higher the frequency, the more is the force of the sound wave produced up to 12,000 cycles or more, depending upon various factors involved. As the speaker will carry no direct current, it must be operated through a condenser in conjunction with the main speaker as shown in the diagram of Fig. 15. It has an extremely high impedance—often as high as 500,000 ohms. These units are connected to the cone or diaphragm in the same manner as the magnetic motor with the exception that there is no control spring required. One fault of the crystal motor is its inability to withstand sudden mechanical shocks and occasional overloads, and sudden electrical impulses will often cause the crystal unit to break or rupture itself.



This view shows a twin unit speaker. The larger unit is for the lower range of frequencies while the smaller unit is the tweeter for higher frequencies. Note how one mounting serves both speakers. Courtesy of Cinaudagraph.

Some of the lightest weight high quality headphone sets make use of the crystal motor. These complete units, including head band and cord, are made weighing less than six ounces. Their light weight enables operators to wear them for longer periods without fatigue.

Several units are made slightly larger than headphone units to attach to small horns. These small speakers are usually used as *tweeters* or high A.F. (10,000 to 20,000 cycles) reproducers in conjunction with other low A.F. speakers and a *divider* network to attain a greater range of sound reproduction as in sound picture theater equipment. For example, the output of an A.F. amplifier is fed to a frequency discriminating network arranged so that all frequencies below, for example, 2500 cycles are fed to the large low frequency speaker, and all the frequencies above 2500 cycles are fed to the tweeter. The frequency at which one speaker ceases to reproduce and the other starts to reproduce is known as the *cross-over* frequency and is chosen so as to be within the lower response of the tweeter and the upper response of the *low* speaker. Using such an arrangement allows a greater band

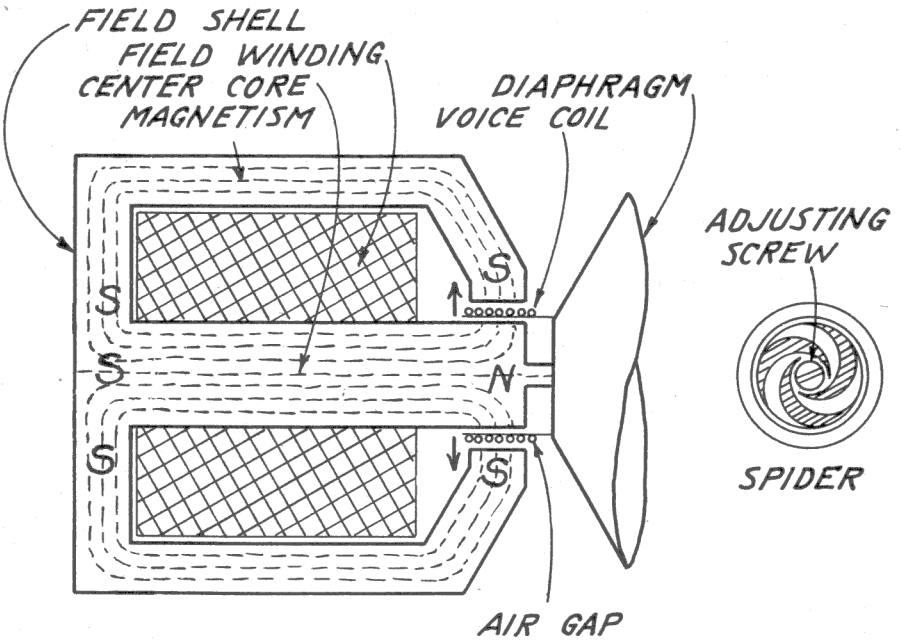


FIG. 16

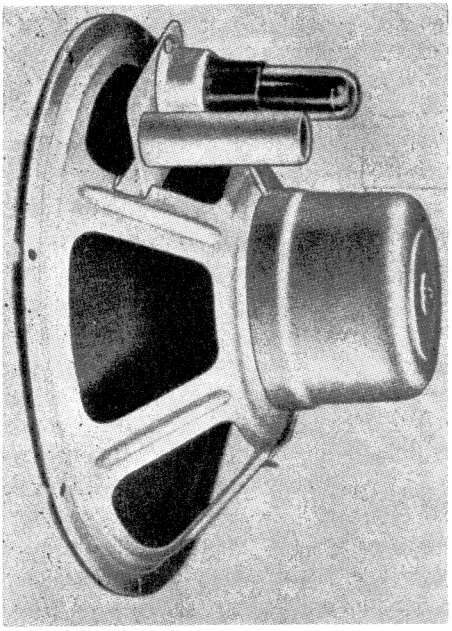
of A.F. frequencies to be reproduced than most individual speakers will cover.

You are now familiar with the possibilities and some of the faults of these early reproducers. There are many special applications in which one of the motor type speakers would be ideal. For the most part, however, modern design practices use the *electro dynamic speaker*.

ELECTRO DYNAMIC SPEAKER

Very few magnetic type speakers can produce more than ½ watt of sound, but many dynamic speakers in average radio sets regularly handle 5 to 10 watts and more. Changes in speaker design to make the electromagnet principle practical were, of course, necessary. The most important advantages, such as the elimination of dead weight attached to the cone and the reduction of inertia due to moving parts, will become evident to you as you follow this lesson. Dynamic speakers will also withstand quite severe electrical and mechanical shocks.

With reference to the cut-away view of a typical dynamic speaker in Fig. 16, a soft iron circular shell fitted with a central cylindrical pole piece forms the basic magnetic circuit with a small circular gap marked *air-gap*. The projecting end of the pole piece may be anywhere from one-half inch in diameter to over two inches in diameter. The air-gap is always small, ranging from less than 1/16th inch to slightly more than 1/8th inch. It is simply large enough to admit the *voice coil* and its winding form which is directly and securely attached to the diaphragm *without touching* the shell or center pole.



Above is shown an electrodynamic speaker with an integral rectifier unit which furnishes field current for the electromagnet. Such rectifier units avoid the use of long field coil leads. Courtesy of Cinaudagraph.

The voice coil is nothing more than a small coil of copper wire wound on a suitable insulating form. This, in turn, is attached to the cone or diaphragm by means of cement.

The coil may have anywhere from one to over a hundred turns of wire on it—this will be explained in detail later. These turns of wire are wound in the same direction so that the magnetic field, created by current flow through them, will accumulate in one direction. A field coil, consisting of many thousands of turns, for an A.C. receiver, consumes practically all of the space provided for it in the shell as indicated in Fig. 16. *Direct current* is made to flow through the field coil and *magnetizes the shell very strongly.* Because of the mechanical construction, *a very strong magnetic flux is made to concentrate across the circular air-gap.* This is done by tapering the edges of the outside shell pole piece. When a voice coil carrying signal current is placed in this strong flux, the field of the wire itself reacts on the flux, causing a strong mechanical thrust or urge of the voice coil and its cone in a direction parallel to the center pole axis. If the field magnetism is held constant, which is the case, and a varying signal current is fed through the voice coil, the latter will move in exact accordance with the intensity of current passing through it. Being integral with the diaphragm (cone), the voice coil and cone *will move as one piece and sound waves will be created.* Just enough space is left on each side of the voice coil and its winding form to permit it to move along its axis without touching either side of the shell or center pole piece. To allow the voice coil or its form to touch the magnetic structure would be worse than to let the armature of a magnetic speaker touch each pole as it vibrated between them.

The purpose of the spider, Fig. 16, is to mechanically hold the voice coil in the *exact center of the magnetic gap.* In the direction of movement of the voice coil, the spider is made very flexible by spiral or other perforations and thus is not allowed to contribute to the production of sound. Some of the spiders are solid but flexible membranes. The hole in the center of the spider is purposely made slightly larger than the screw which retains it for the purpose of adjusting the voice coil

when necessary. To insure the proper adjustment of the voice coil, loosen the center screw and insert three ¼ inch strips of an ordinary calling card or speaker shims in between the voice coil and the center pole piece. This will force the voice coil in a central position with respect to the pole piece. Tighten the center adjusting screw and remove the shims making sure that the cone does not slip while this is being done. The voice coil may warp or wear out of place or slip due to vibration, and this method is provided for readjustment. In other respects, the diaphragm or cone is like those used for the magnetic type speaker. Here again the magnet assembly may be mounted on either side of the diaphragm although generally it is placed on the convex side. In some of the larger speakers, the movement of the voice coil may attain as much as ½ inch total lateral amplitude. In one form or another, all dynamic speakers are like this. It must always be remembered that small particles of dust or other material, if allowed to get in between the voice coil and poles, will interfere with reproduction and often damage the speaker. This is especially true of magnetic particles such as iron filings, etc. Provisions against this are usually incorporated in the speaker, and the service man *must* guard against the entrance of such particles. Often a piece of felt is cemented over the spider front openings to prevent the entrance of dust particles and iron filings.

The supply of the voice coil with an A.F. current and the supply of the field coil with direct current for the production of strong magnetism will now be explained.

One point is quite important in connection with speaker fields, and this must be thoroughly understood before going further with this study. The maintenance of a fixed magnetic field requires no energy. Of course, in practice, a little energy is lost as there is no such thing as 100% efficiency as there is always some amount of loss in an electrical circuit (IR loss due to resistance). It requires some amount of electrical energy to build or produce a magnetic field, but once this is accomplished, very little energy is required to maintain the action.

The strength of the magnetism of any electromagnetic field, of which the speaker field is a good example, depends on the amount of current flowing in the windings of the device and the number of turns in this winding. More accurately, the strength of the field is proportional to the *product* of these two factors. Since current is measured in amperes or fractions thereof, it is usual to refer to the magnetism as being determined by the AMPERE-TURNS of its winding. As long as this product (amperes times wire turns) is as high a figure as required for the field, it makes no difference whether use is made of a high current in amperes or a large number of turns. In fact, it is good practice to make them both as large as possible to meet a given set of conditions.

Because of this fact it is just as possible to operate a speaker field from a 6 or even 2 volt source as from a 110 or 220 volt source.

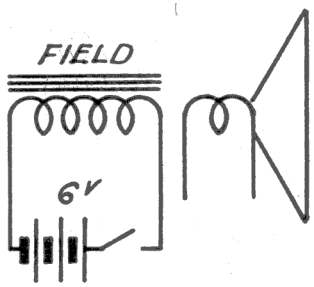


FIG. 17

Moreover, only a small fraction of the power drawn by the field is used for actual magnetism, as most of it is used to overcome the resistance of the winding. When operation gets under way, the power or the heat radiated by the speaker field is practically equal to the power drawn from the source, there being almost none used for magnetism. For this reason, speaker fields are often connected as resistors in series with some useful circuit, so that the field will do some useful work instead of wasting energy in heat. The following will explain the various methods of connecting the fields.

HOW THE FIELD WINDING IS ENERGIZED

When no other methods were available, storage batteries were used to supply field current to dynamic speakers, and because this is acceptable, the most modern auto receivers use this method of field excitation. Figures 17, 18, 19, 20, 21, 22, 23 and 24 show all of the practical or standard methods of speaker field supply. In Fig. 17 the automotive type is shown. The wire used is large in this case, ranging from number 10 to 14 and may include up to several hundred turns. The field carries from ½ to 3 amperes. For receivers designed for 32 volt farm lighting plants, the field is wound with quite a few more turns of smaller wire carrying somewhat less than ¼ ampere as a rule This circuit is represented in Fig. 18. Still another way to provide direct current for the field of a dynamic speaker is to use the direct current produced by the high voltage rectifier of the receiver whether it be of the A.C. or D.C. type.

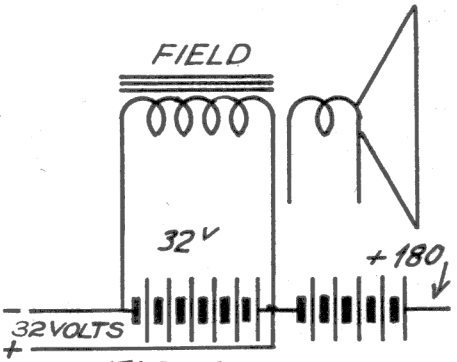


FIG. 18

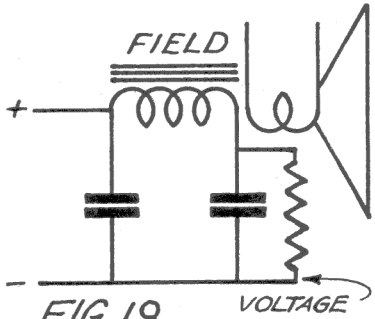


FIG. 19

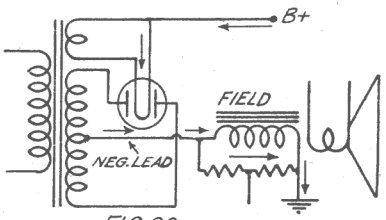


FIG. 20

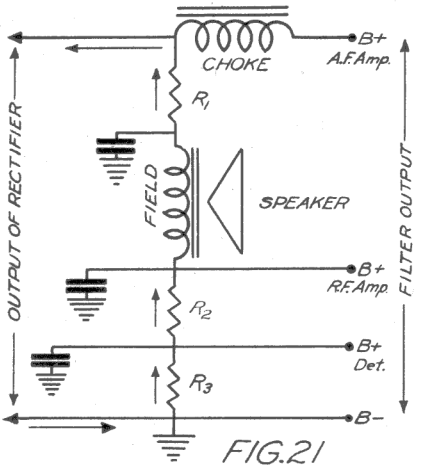


FIG.21

It was discovered early in the progress of radio that in addition to acting as a field for a speaker, the same coil winding would also serve the purpose of a filter choke for the power supply. As a result, most of the small A.C. operated sets of today use the speaker field as the only filter choke. In this case, the field winding is wound with many thousands of turns of very fine wire, sufficient to carry from about 40 to 200 milliamperes of current. It is placed in the *positive lead* of the main high voltage power supply, as in Fig. 19, or in the *negative lead,* as in Fig. 20. Arrowheads in the latter figure indicate the direction of current flow. In some cases, the field winding is placed directly across the high voltage—thus serving as part of the voltage divider. See Fig. 21. It may also become part or all of the voltage divider in series with either the positive or negative lead of the power supply. This is particularly true of universally operated (A.C.-D.C.) radio sets. One arrangement of this type is shown in Fig. 22 with one rectifier plate-cathode providing the field current

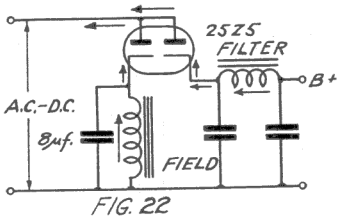


FIG. 22

for the speaker while the other plate-cathode provides rectified current for the tubes in the radio set.

If it is desired to connect a dynamic speaker to a receiver which is not designed for this type of speaker, it will be necessary to supply the field coil independently of the power supply for the radio set. For this purpose, a separate high voltage rectifier is sometimes used and connected as at Fig. 23. The usual full-wave high voltage rectifier, such as the 80 tube, is used in this circuit.

Still another type of rectifier for the speaker field which is more rugged than the tube rectifier is the bridge dry-disc rectifier shown in Fig. 24. You will remember you studied this type of rectifier in the lesson on meters. An externally excited field for operation directly on the 110 volt D.C. line also may be arranged. This type would appear the same as those shown in Figs. 17 and 18 with the exception that a filter condenser would be connected across

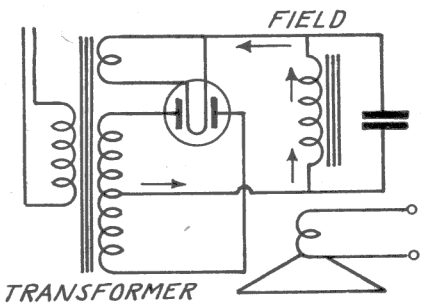


FIG 23

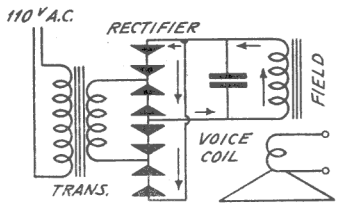


FIG. 24

the field winding for filtering. The field winding in Fig. 24 is large with relatively few turns as compared to the one in Fig. 18, as the dry-disc or copper oxide rectifier is a relatively low voltage device. The automotive type field winding may, if necessary, be operated from an A.C. 110 volt line by using a step-down transformer and dry-disc rectifier.

VOICE COIL REQUIREMENTS

There are two factors which definitely limit the size of the voice coil in a dynamic speaker unit. These are (1) the weight of the voice coil, which must be kept at the lowest possible minimum, and (2) the space for the coil in the air-gap must be as small as possible to permit the strongest possible concentrated magnetic field across it. This makes it imperative that the voice coil be wound with as few turns of wire as possible. One manufacturer used a single turn of copper in the form of a collar for the voice coil, feeding this from one or more turns of heavy copper wound around the output transformer. Another uses a single turn of aluminum wire for the voice coil. The general rule however, is to use 20 to about 50 turns of fairly large wire for the voice coil.

A little reflection on this matter will show that the voice coil, which must handle the maximum power of the set, must be supplied with power in the most efficient form. An output tube may supply power at 100 or 200 volts, but with only 15 or 20 milliamperes of current. Now the voice coil can make use of the most power at a very low voltage but with a higher current value. That is, about 5 or 10 volts (average) with several hundred milliamperes of current flowing. The reason for this is that the voice coil impedance must remain quite low because of the few turns of wire involved. Voice coil impedance values average between 6 and 15 ohms because of their relatively short lengths. It is, therefore, necessary to convert the power at *high voltage and low current* from the output tube or tubes to *low voltage at high current* for the use of the speaker.

The only way that it is possible to make this change is to convert the power into a different form of energy (magnetic energy in this case) and then convert it back again having the correct voltage and current specifications. A transformer is used for this purpose.

An out-put step-down transformer wired to a triode output tube and to a dynamic speaker voice coil is shown in Fig. 25. If it is assumed for the moment that the output tube is a type 2A3, having a plate resistance of 2500 ohms

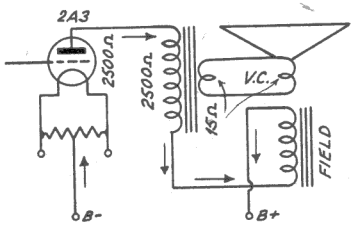


FIG. 25

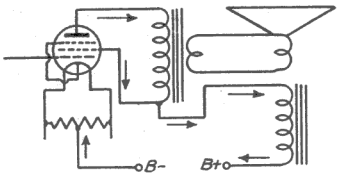


FIG. 26

as given on any tube chart, an output transformer must be used having a primary impedance of 2500 ohms also. This insures that the transformer is drawing or taking all of the power developed by the tube intended for the output. If the impedance of the primary of the transformer is either greater or less than 2500 ohms, the transformer will be less efficient from the viewpoint of the amount of *power* it will transfer from one circuit to another. It will draw less than the total power it should draw at a rate depending on its impedance value.

The secondary of the output transformer, often referred to as the voice coil winding of the transformer, has an impedance, for example, of only 15 ohms and is wound with only a few turns of wire. This is done so that the characteristics will match those of the voice coil which also has an impedance of 15 ohms in this case.

For this transformer, the primary impedance is 166 times the secondary impedance, that is, $15 \times 166 = 2500$ (approx.). Or, 2500 divided by 15 equals 166. The turns ratio of the transformer is the square root of this factor (166) or approximately 13. This means that the primary winding has 13 times as many turns as the secondary. If the primary winding has 1300 turns of wire on it, the secondary must have 100 turns under this condition. There are 13 turns on the primary for every turn of the secondary. In this way, maximum power may be transferred from the output tube to the speaker and designers take these facts or basic laws under consideration when designing a given transformer.

TYPICAL OUTPUT CIRCUITS

A pentode tube output circuit, typical of those used in midget receivers, is shown in Fig. 26. The transformer, in this case, is matched to the tube for maximum power transfer and to the voice coil as well.

In modern design it is often convenient to mount the output transformer on the speaker frame or chassis. The speaker is then connected to the radio set by means of a five- lead cable as shown in Fig. 27. The two additional leads (F)

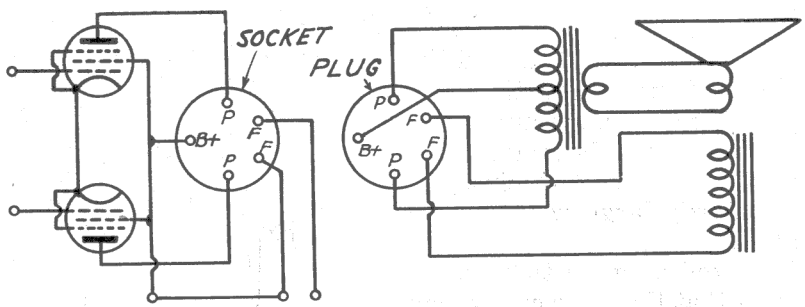


FIG. 27

are provided for the field. The diagram shows a push-pull output pentode circuit feeding a dynamic speaker.

Since the field of the speaker carries the high voltage D. C. while it is filtering it, there is naturally some current ripple or variation in the current passing through the field coil. Together with a magnetic flux, due to the signal in the voice coil, this will result in a hum in the speaker. Even without a signal, enough current may flow in the voice coil circuit, due to induction, to cause considerable hum in some types of speakers. This is especially true in the well-designed high fidelity speakers which are made to reproduce well the lowest possible frequencies in the A. F. range.

To overcome this difficulty a special coil is wound on the field pole similar to the voice coil, but in the reverse direction. This coil is wired in series with the regular voice coil, as shown in Fig. 28. In this way the hum *component* of the field winding is magnetically balanced out or neutralized. That is, an equal or opposite magnetic field is produced cancelling the original one produced by the speaker field.

The voice coil connecting leads must be quite flexible to allow the voice coil to vibrate and respond to the signals fed to it. If a receiver is completely dead, it would be well to check the continuity of the voice coil and inspect the leads carefully for this defect. Constant vibration often causes this trouble. It will do no good to test the voice coil when connected as the transformer secondary is in shunt with it. Even if the voice coil is open, the secondary will show a *closed circuit.* The difference between a good winding, either for the voice coil or for the transformer winding, and a short will not be apparent with an ordinary ohmmeter. Both coils will test practically zero ohms. The best method is to disconnect the voice coil circuit from the output transformer and test directly across the two free leads. When this shows *closed circuit,* reconnect and test for a signal fed to the transformer. Experience shows that more trouble is likely to develop in the field, or the transformer primary, as these are much more delicate windings than the voice coil or transformer secondary.

PERMANENT MAGNET DYNAMIC SPEAKER

For purchasers of receivers having no source of electrical power in their homes, the P. M. dynamic speaker is quite popular. It consists of a field made with a *per-*

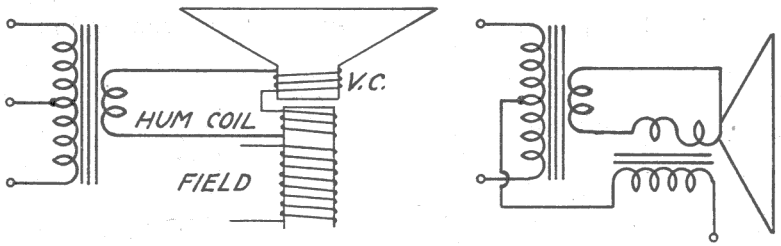


FIG. 28

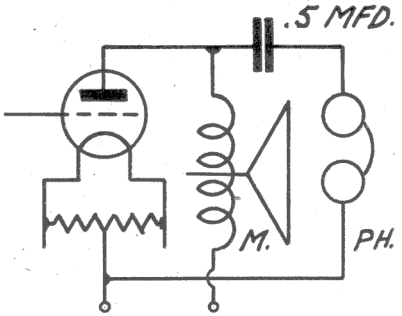


FIG.29

manent magnet instead of an electromagnet but with the regular voice coil as for the regular dynamic types. Otherwise the P.M. and electrodynamic speakers are exectly alike. The use of P.M. speakers has increased largely due to their less total weight and their lack of hum, due to the A. C. ripple in field coils. In installations requiring more than one speaker, the use of P. M. speakers simplifies the external wiring and does away with the necessity of separate power supplies to each speaker. Small P. M. speakers (diameters from 1½ inches to 5 inches) are often used in *talk-back* or call systems where they may also function as *microphones*. The popular *Handy-Talkie* of the Army uses two tiny P. M. speakers—one as a microphone and one as the reproducer.

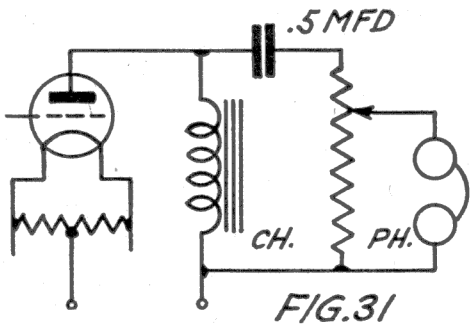


FIG.31

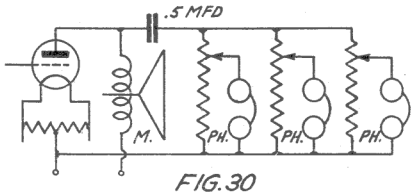


FIG.30

MULTIPLE SPEAKERS

It often becomes necessary to connect more than one speaker or pair of headphones to one receiving or public address system. A large variety of combinations are shown in Figs. 29 to 36.

Single and multiple headphone and magnetic speaker combinations are shown in Figs. 29, 30 and 31.

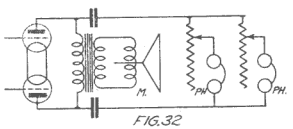


FIG.32

For push-pull circuits, arrangements as in Fig. 32 are used. Although a magnetic speaker is shown here indicated by M, dynamic units may be connected in the same manner with proper provisions for the field coil. To connect a magnetic speaker to a receiver already using a dynamic, connect as in Fig. 33. Or, to connect a number of magnetic speakers or phones or some of each to a receiver having a dynamic speaker make your connections as in Fig. 34.

In Figs. 35 and 36 are shown two ways of connecting two dy-

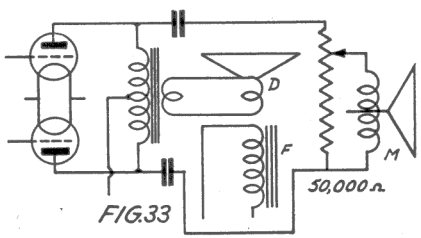


FIG.33

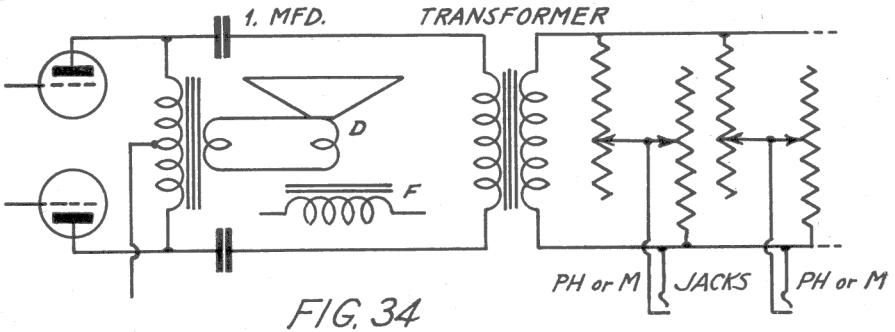


FIG. 34

namic speakers to a single output system of the push-pull type. Fig. 35 shows the *series* method of connecting the voice coils while Fig. 36 shows the *parallel method.* The single stage output method would be the same in each case except, of course, the primary of the output transformer is a single winding.

In many cases it is desired to have a remote speaker, perhaps in some other room and be able to cut it off without affecting the one attached directly to the radio set. This may be accomplished by using a switch as shown in Fig. 37. When it is desired to cut either speaker on or off, a switching system in the voice coil is used as in Fig. 38.

SPEAKER PHASING

It must be remembered that when two speakers are used together and at the same time, their diaphragms must both move in and out at the same time. If one diaphragm is moving out while the other is moving in, one speaker will partially destroy the sounds produced by the other. The effect is as though a poor baffle or no baffle at all were used for only one speaker (baffles are explained further on). To make the speakers act correctly in this respect, the plate current of the output

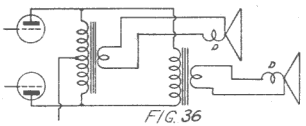


FIG. 36

tubes should be interrupted and the direction of the diaphragm movement noted. For push-pull circuits this will not work, so a dry cell or some D.C. source should be connected to the voice coils as in Fig. 39, noting the direction of the cones when both are connected. If one cone moves in, as detected by touching it when the cell is connected, reverse the voice coil of *one*

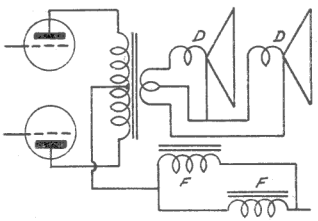


FIG. 35

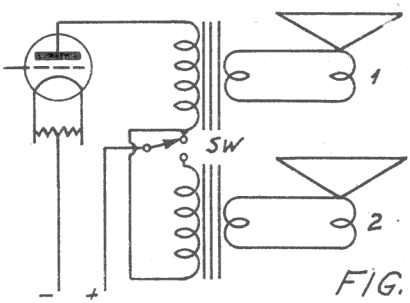


FIG. 37

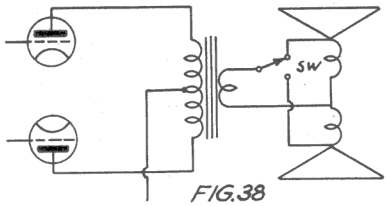


FIG.38

of them as shown in Fig. 40. They will then move in the same direction. This procedure is called *phasing* of speakers.

Most all of the large dynamic speakers capable of producing good strength of sound at very low frequencies (around 50 to 100 cycles) have the common shortcoming of failing to reproduce the very high frequencies. If these are left out of the signal, it will sound very unnatural. A practical limit seems to be reached at between 5000 and 8000 cycles. Even above 2500 or 3000 cycles, the volume drops off fairly rapidly. The mass of the cone and voice coil assembly is largely responsible for this and nothing can be done with the speaker for as soon as it is made to favor the high frequencies, it will no longer take care of the low frequencies. For this reason multiple speaker systems are used in the better class receivers. The large speakers handle the low tones or frequencies, and the small speakers handle the high tones or frequencies.

The high frequency speakers will reproduce nothing below 1500 cycles but will do very well up to 20,000 cycles or more. Many of

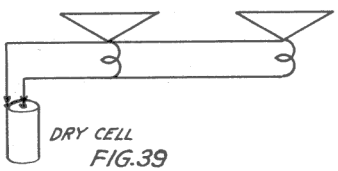


FIG.39

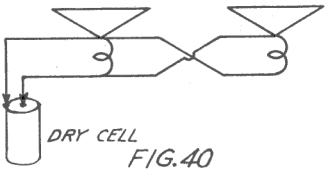


FIG.40

them start at 9000 cycles at the point where the other speaker rapidly cuts out and continue on up to 15 or 16 KC. This takes in a range of sound waves well above the average person's ability to hear. The two speakers together form the ideal reproduction system. Characteristic curves of the frequency and power reproducing abilities of each speaker of such a double set-up are shown in Fig. 41. The individual characteristics of the large speaker represented by A combine with those of the small speaker, *tweeter*, shown at B to form a reproducing characteristic C which is due to both speakers.

The higher frequency, or tweeter speaker as it is sometimes called, is made very much like the large speaker but very much reduced in size. There is no important difference other than this between the two.

There are many different forms of cones used for speakers, the more important of which are pictured in cross section in Fig. 42. the sharp angle cone as in A was quickly done away with for its area per unit volume of air moved was too great, making it inefficient. Moreover, it did not press the air straight forward but *slid* by it thus increasing the inefficiency. If the cone is not made too flat or just about the proportions of B, the qualities of rigidity were preserved as in A, and the additional advantages of minimum

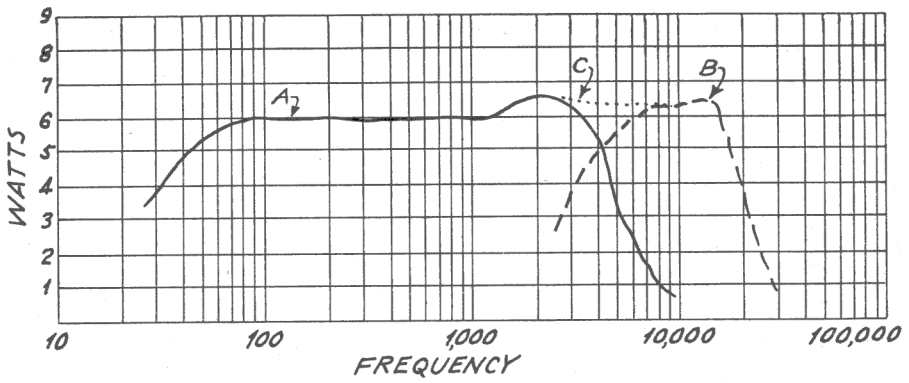


FIG. 41

area per unit volume of air, lightness, direct pushing of the air and large diameter of cone are gained.

Because of the inability of the cone of a large surface area to displace this large amount of air very rapidly or at a high frequency, some of the designers placed circular corrugations around the cone as in C of Fig. 42. Thus, the voice coil and inner small section of the cone could move independently of the rest of the cone to some extent, thus favoring the high frequencies. The fidelity of general characteristics of such a cone were considered superior to the former types. As there are other methods of producing the same results, this is not a general practice. A later type of cone to make its appearance on the market is the exponential type as at D. The reduction of air volume within the cone and the lateral flexibility of the cone are considered to give it better fidelity properties. As these things depend more on individual design than on popular practice, it is not possible to make an accurate statement of superiority of these types, although it is universally admitted that the sharp cone at A is inferior.

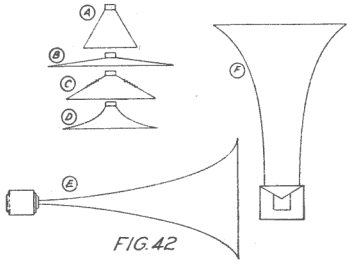


FIG. 42

For projecting sound at a distance, a horn is very often used. This may be of the morning glory or exponential type, as E of Fig. 42, or of the box type either with straight sides or curved as shown at F in Fig. 42. For E a corrugated aluminum diaphragm of the disc type is used, and for F a regular standard cone type speaker is used inside the box enclosure.

BAFFLES, CABINET RESONANCE, ETC.

Because of the effects of baffles and cabinets which alter, to a large extent, the sounds produced by all types of speakers, it becomes a study subject of importance. As has been stated, both sides of a diaphragm or cone compress and rarify the atmosphere close to it alternately. Thus, energy in the form of sound is given off from both concave and convex sides of

the cone in a speaker. At first thought it would seem advantageous to enclose one side of the diaphragm so as to allow only the sound from one side to create waves. Ordinary reasoning will enable you to see that if a cone is moved in one direction suddenly and produces compression on its forward face, it would, at the same time, produce rarefaction on the opposite side. Since on both faces, sound waves are produced equally but in opposite directions (out of phase), they would tend to neutralize each other especially at low audio frequencies. As was stated at the beginning of this lesson, sound travels approximately 1080 feet per second. Simple division gives the wave length, in feet, of sound. For example, at 100 cycles, the distance from the beginning to end of one complete cycle would be 1080/100 or 10.8 feet. Since sound waves travel in all directions from a source, it is reasonable to assume that with a cone without a baffle the sound from one side would cancel or partially oppose the sound from the other by merely travelling around the edge of the cone. If, a box or enclosure is built covering one face of the cone, this cancellation will be eliminated. However, if this were done, the presence of air in the enclosure would act as a cushion tending to prevent the motion of the cone. Ventilation must be provided to eliminate the *back pressure* and the vent holes must be small enough to prevent any large quantity of sound to escape. Another difficulty encountered here would be the resonance or rumble produced by sound reflections *inside* the box or enclosure. This would have an effect similar to that noticed when a person talks with their head in a barrel. It is the result of cancelling the higher audible frequencies (which give clear enunciated sounds) and leave only a rumble. These troubles can be largely eliminated by installing the cone in a baffle of large surface. The size of this baffle should be such that it is at least twice the diameter of the cone on a side. To be more accurate, the distance measured from the center of the cone on one face around the edge of the baffle to the center of the cone on the opposite side should be slightly over one-half of the wave length of the lowest frequency to be reproduced. Many *tricks* are employed in preventing distortion of this type. The most efficient baffle from all standpoints would be of infinite size so that no sound could reach the front from the rear and so that no back pressure or cushion effect would affect the motion of the diaphragm.

Baffle boards as used in receivers for the home with speakers mounted directly behind them are shown in Figs. 43 and 44. One is the vertical type and the other the inclined type. A baffle board is a necessary adjunct for any speaker. It prevents the sound waves produced in back of the cone from interfering and distorting those in front of it. It was mentioned before that sound waves emanate from either side of the cone. Those in back of the cone will seriously interfere with those in the front if they are not deflected or destroyed by absorption. They contain compressions of the

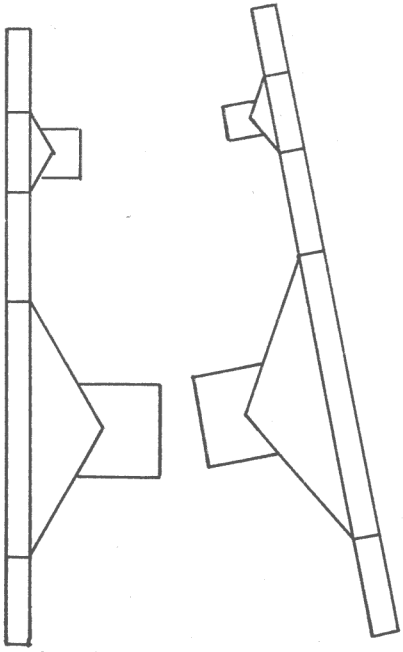


FIG.43 FIG.44

air at the same instant that those in front contain rarefactions and, hence, would tend to destroy one another if allowed to come together. They are said, technically to be in reverse phase with respect to one another.

The baffle board must extend away from the entire cone with no air space through to the other side of its surface. It should be soft or porous for best results and must extend in every direction from the cone, a distance equal to the diameter of the cone or more. If, as usual, the baffle forms the front of the receiver cabinet, being continued around with complete enclosure of the back of the speaker, the baffle need be of no particular size.

Cloth, as well as a rigid grill work, is placed over the cone for protection from hard or sharp objects and dust which might get in the voice coil and air-gap. If the receiver cabinet is closed in the back, it should be lined with celotex, felt or soft cloth to prevent vibration of the cabinet due to the sound waves produced in back of the cone. As an alternative, it may have a sound absorbing *labyrinth* which is simply a *muffler* applied to the radio acoustical problem instead of that of exhaust gas. If the cabinet is open, it should not be placed directly against a hard wall because this leaves no air space to cushion the back sound waves.

CAPACITY OPERATED SPEAKERS

Electrostatic lines of force extending between two conductors exert an attraction force if the conductors are of *unlike polarity* and a repulsion force if of *like polarity*. This is simply a review and a reminder of principles you have already learned. However, this principle is used in the construction of the capacity type speakers. The signal voltage is fed to two plates —one of which is *rigid* and the other of which is *flexible* and moves to and from the rigid plate, according to the voltage impressed between the two at any moment. Practical applications of this type of speaker were very unsatisfactory and they never reached wide use.

The actual construction of this type of speaker took several forms. A back plate of rigid conducting material and perforated, formed one electrode while a flexible diaphragm was stretched in front of it leaving an air space of only a few thousandths of an inch. (See Fig.

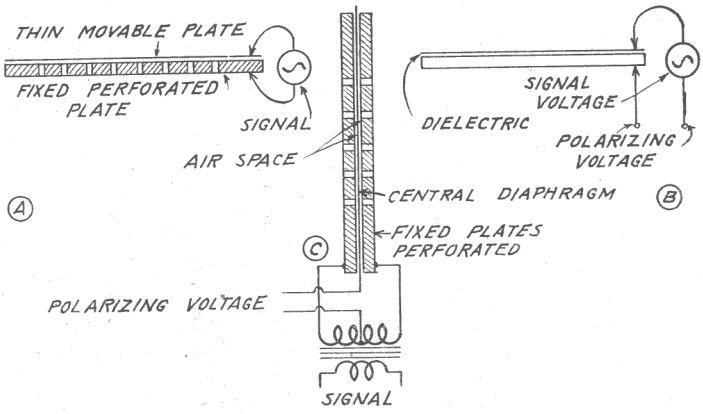


FIG. 45

45). The flexible plate will follow the signal variations and produce sound accordingly. To prevent serious distortion due to frequency doubling of the sound, a polarizing voltage (D.C.) must be used in series with the A.C. signal voltage so that the polarity of the plates will never reverse. The intensity of signal voltage will simply vary the attraction of the plates rather than change their polarity. Since attraction of the plates will result with either polarity, the polarizing voltage is absolutely necessary. This polarizing voltage must be higher than twice the peak voltage of the signal at all times.

To prevent the two speaker condenser plates from touching on strong signals, a dielectric was introduced between the plates in one model of this type speaker. See Fig. 45B. It consisted of a soft rubber membrane. In other cases, the fixed plate was ground in spherical form so that the distance of the diaphragm from the plate was somewhat larger at the center than at the edges to allow for considerable displacement of the diaphragm without actual contact.

A double back plate unit was developed with a diaphragm stretched between with the signal voltage applied to the two back plates and the polarizing voltage applied to the central disc. These three condenser speaker units are shown in Fig. 45A, B and C.

These questions are desigend to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. Why is a permanent magnet used in a headphone unit?

No. 2. How would you identify a magnetic or a dynamic speaker?

No. 3. Why is it desirable to prevent the flow of direct current through magnetic speakers and headphones?

No. 4. Describe three ways of exciting dynamic speaker fields with D.C.

No. 5. Why must an output transformer always be used in connection with a dynamic speaker?

No. 6. Name four different types of speakers.

No. 7. What is meant by PHASING of two or more speakers?

No. 8. What is the main advantage of using two speakers for a single set or system when one will provide enough power?

No. 9. What may be done to prevent hum due to the speaker field carrying pulses from the rectifier?

No. 10. What three purposes can a dynamic speaker field serve simultaneously?